"HEARING" THROUGH THE SENSE ORGANS OF TOUCH AND VIBRATION

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Professor of Psychology, Northwestern University, on Leave with the National Research Council

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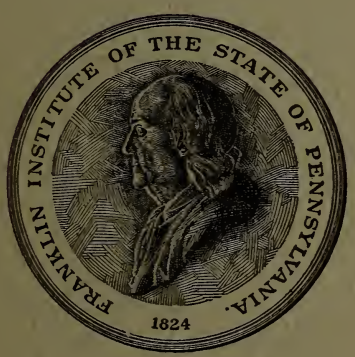

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I.

A HALF century ago Alexander Graham Bell and his associates were dreaming of what has become the omnipresent telephone; dreaming and laboring, too. The uninformed and unimaginative were smiling indulgently. Was it not a bizarre thing—the notion that a man in his shop might talk into a machine and be heard and understood next door?

It was unthinkable that a battery and a long wire should carry speech to an ear. It might be an interesting plaything for amusement within a gentleman's house and premises, but beyond that, an extravagant gesture.

Now the telephone is here and so is wireless telephony. We talk to London. We accept it as a matter of course. It is almost as near to us as hands and feet.

And here is another extravagance! A bit of pioneering that has been hitherto unventured.

I am using the principle of the telephone, together with amplification, experimentally in relation to understanding so complicated a thing as spoken language when it is carried as vibrations instrumentally to the skin of one or of several persons at once and felt as something vibrating against the skin. It is a successful experiment.

This same extravagance relates to the use of the feel of words and of connected discourse as a means for the correction of defects in speech such as those that occur in semi-mutes. Here is a door newly ajar into the applied science of phonetics.

Is it possible to feel musical sounds also and to enjoy them by feeling them? Experiment alone can answer. Preliminary work in this direction has elicited a favorable opinion.

* Read before The Franklin Institute, March 24, 1927.

Of course it is not "hearing" that I am talking about. That is a figure of speech. It is *feeling* speech and musical sounds through the organs of touch in the skin and through the organs of the sense of vibration; distinguishing the feel of one word from the feel of another and associating meanings with different "feels" exactly as we associate meanings with different sounds. There is nothing more mysterious about knowing a spoken word by its feel and about recognizing differences in pitch by their tactual qualities than there is about knowing a cake of soap in the dark by its feel.

I set out upon this adventure more than four years ago. At present, and during the last three years, it is under the auspices of the National Research Council. At the outset of the venture a speaking tube was extended through two walls in the intervening room. A student—now one and now another—held his hand tightly over one mouth of the tube. I discovered that when the vibrations of air from an experimenter's mouth in the act of speech were thrown into the farther end of the tube the student could feel the quivering air within it. Then I found that he could distinguish one word from another and ultimately he could identify members of a group of thirty-eight different words. That gave me a start, though it was a very crude one, in a virgin field.

Electrical appliances were then substituted for the tube. The first instruments were rough enough. They have been improved.

Remember that the skin was the original ear. If James Harvey Robinson in writing his "Mind in the Making" had gone back farther than he did go toward the beginning of the development of thought and prejudices, he would have observed that the most primitive man did not hear with his ears and obtain original data through that source, for the mollusk of old, like the mollusk of to-day, had skin and no ears. He *pricked up his skin* and *felt* his environment.

In this adventure we are, in other words, going backward over the genetic history of our organs of sense to the great, undifferentiated "mother sense of them all," and we are looking forward to a time when those who are bereft of the most complicated organ of touch—the hearing ear—may fall back upon the very base of the sense of reality in the extended array of organs of

touch in the skin. From an unaccustomed angle we are here entering upon the great archæological field of the psychologist.

Before I get beyond preliminaries I should say a little at least in reply to the inevitable query from the uninitiated: "How do you get your speech over to the 'listener's' skin?" Later in the course of this paper I shall go into some detail in answer to this question.

Imagine a group of persons, each of whom holds a vibrator in his hand. Each device is analogous to the ear-piece in a radio set. In its own place each one serves the same purpose. Through suitable batteries and an amplifier these devices are connected with a transmitter or microphone. Now assume a speaker; let him be out of the subjects' sight and any distance away, if only he is before the transmitter so that his vocal vibrations beat upon it. Then the moving element in each vibrator hidden in the hand of the "listener" begins to work against his finger-tip and he knows at once that something is "going on." Now, if the speaker's assistant before the eyes of the subjects will use a blackboard, a piece of chalk and a pointer, they—the "teletactile auditors"—will soon discover that one thing happens against their finger-tips when the word *a* falls from the speaker's lips into the transmitter at the other end of the system, and another thing when *o* is uttered, and quite a different thing when the word is *elephant*. In like manner to the end of the alphabet and dictionary. By and by, the folk who are holding the vibrators can get on without the assistant and his blackboard and can travel the road alone.

II.

My experiments are of primary interest to psychologists and physicists. They reveal an undreamt of capacity for refinement of discrimination within the realm of the senses of touch and vibration. They demonstrate the possibility of using these senses as the base of supplies for the process of integrating a language sense. We are here substituting one sensory function for another —a process, the like of which, we have been studying anew since the war. I will trace the larger outlines of my results.

(1) Two deaf people who had been working in my laboratory during an aggregate of 290 and 280 hours, respectively, to May,

1926, were able in that month to pick up a story from the feel of it when the speaker was out of sight. This is no more uncanny than is learning to know any other thing in the dark by its feel.

(2) Other subjects, less experienced, have learned to recognize many sentences, words, certain vowel and diphthongal qualities when they stand alone, and to make a fair showing at identifying these elementary qualities when they are found in words that had never before been felt as words.

(3) I have demonstrated an improvement in speech on the part of my deaf-mute or semi-mute cases; in the modulation and lilt of the voice; in emphasis, rhythm, accent and tempo. In enunciation, too. The feel of the movement of speech gets "into their bones." Then they speak better than they formerly did. And that is not extraordinary. The rôle of the kinæsthetic sense in the psychology of movement is in the psychology of speech, too. Speech is a form of movement. We dance as nicely as we do because we have the feel of the music in our bones. When a deaf person speaks a given phrase through a microphone against his own skin he is able to compare the feel of his own voice with what occurred a moment before when the experimenter uttered the same phrase. He thus obtains an intimate feeling for the way speech normally runs along through cadences and tempos from phrase to phrase. It is a vivid experience for him. Out of it come cues to guide him in his own speech.

Between January 26 and March 4, 1927, one subject made an improvement of 38 per cent. in speech—measured by the accuracy with which strangers out of her sight could understand and report what she was reading aloud. She had already graduated from a school for the deaf and was having no training outside our laboratory.

(4) We have demonstrated an improvement in reading capacity in the course of an aggregate of no more than twenty hours of laboratory training.

(5) One case without hearing and without vision of the speaker's face attained to perfection in recognizing 120 colloquial sentences when she had felt each one but nine times; thirty to-day and thirty to-morrow till the whole series had been finished; then another going-over in a different order. Others in the same time attained to from 60 per cent. to 90 per cent. of perfection. After

the ninth reading 72 new sentences were mingled with 108 of the old ones without the subjects' foreknowledge. On the first trial thereafter the most successful case not only recognized new sentences as new, but she interpreted 28 of the 72 new ones in addition to the 108 old ones.

This is not the knowing of so many scores of isolated words by feeling them. It is the recognition of some words as such; of many vowel and diphthongal qualities, and of many more

TABLE I.

Improvement in Reading.

Subject.	November 17, 1926.	February 28, 1927.
	Per cent.	Per cent.
O.	80	87.5
C.	82.5	90
S.	62.5	60

Subjects indicating by a check the best of three methods of reading each one of 40 sentences.

S. discontinued laboratory exercises shortly after November 17th.

envelopes or patterns of phrases and sentences as wholes. It is also the interpretation of all these things.

(6) From the feel of the movement of spoken language subjects have acquired some of the thrill of speech. It has been made to live for them. Both prose and verse afford them pleasure, but not all in equal degree. The verses by Southey, for example, on "The Waters of Lodore":

> "How does the water
> Come down at Lodore
> From its sources that well
> In the tarn by the fell"—

are particularly pleasurable. They ask the experimenter to repeat a reading of these verses. They prefer them to the following line from Stevenson, though it is in the same meter as the Lodore verses:

> "How do you like to go up in a swing?"

The only difference between these verses is in the predominant vowel quality. Evidently some vowel qualities are more pleasurable than others. Isn't it odd that one can find pleasure in feeling

TABLE II.

Recognition of Certain Final Consonants and Semi-vowels.

January 21, 22, 24, 25, 26 and February 7, 1927.

Times Given.	*ee*	*eep*	*eet*	*eek*	*eed*	*eel*	*eer*	*eem*	*een*	*eeng*
27	21									6
ee	77.8%									22.2%
28	2	9	6					1	3	7
eep	7.1%	32.1%	21.4%					3.6%	10.7%	25.0%
28	1	11	13	3						
eet	3.6%	39.3%	46.4%	10.7%						
28		1	6	18	3					
eek		3.6%	21.4%	64.3%	10.7%					
28			1	2	25					
eed			3.6%	7.1%	89.3%					
28						16	9	2	1	
eel						57.1%	32.1%	7.1%	3.6%	
28	2					6	17	1	2	
eer	7.1%					21.4%	60.7%	3.6%	7.1%	
28								18	8	2
eem								64.2%	28.6%	7.1%
27	3	1						1	14	8
een	11.1%	3.7%						3.7%	51.8%	28.6%
28		1						1	11	15
eeng		3.6%						3.6%	39.3%	53.6%

In the heavy-boxed squares are the number and per cent. of identification of each stimulus. Other figures represent confusions. Thus the figures 2, 9, 6, 1, 3 and 7 in the second row of squares from the top indicate, respectively, that when *eep* was pronounced, *ee* was reported twice; it was identified nine times; *eet* was reported six times, etc. *Eep* was pronounced 28 times.

such things upon one's fingers? But there are stranger things. What is delectable about a pinch of snuff in the nostril aside from the opportunity it affords to flash a delicately carved snuff-box? I do not know. Some behave as if they enjoy it, and that is the rock-bottom fact. We can learn to enjoy almost anything excepting condescension on the part of our neighbors.

(7) We who hear are deceived if we think we have an ear upon every consonantal quality in speech. What can the fingers do? I have only begun to enquire of my own thumb. On six days, a half-hour session daily, I have tried to identify certain consonantal and semi-vowel qualities following long *e*. A given tactual impression may be any one of ten. I have made identifications of each syllable in a certain per cent. of cases as set out in Table II. When this type of work shall have been completed for all our vowel qualities, both preceding and following consonantal elements, we shall be in a position to offer a satisfactory answer to the consonant query. Meanwhile the outlook is favorable.

I doubt if identification is by means of the quality of a consonantal element as a unit taken alone. Not in all cases at any rate. The judgment is often based principally upon the way in which the tactual quality is cut off and by the interval that lapses between it and what follows or precedes it. As far as we have gone, what follows the vowel is a sharp punch that corresponds to *p* or *t*, or a dull one that occurs with *d*, *k*, or hard *g*. If it is not in these categories it is a slight fading away of the tactual experience, as in final *n*, or a marked fading, as in the nasal *ng*, or a swelling out, especially with the liquid *l* and less of it with *r*, or a longer or shorter interval between what stands for the vowel and what stands for the consonant. This description is based upon experience with a single-unit vibrator or receiver analogous to that in a radio set.

(8) Up to this point I have had in mind a situation in which the experimenter is hidden from the subject. But let him simultaneously see the speaker's face and feel his words. An important result occurs: He can then understand what the speaker says anywhere from 30 per cent. to above 100 per cent. more perfectly than he can do by lip-reading alone, assuming that he has had *only 60 or 70 hours of training*. This is an extraordinarily important point because of its practical bearings. Herein is the possibility of enormously speeding up instruction of the deaf.

(9) Because the deaf can enjoy the feel of verse more or less according to its predominating vowel qualities, why not music? The answer is that they can. When one of them consistently reports to me that he prefers "Old Black Joe" when it is sung into his chest through a vigorously acting receiver that makes

TABLE III.

Order of Difficulty in Recognizing Certain Consonants and Semi-vowels Following Long "e."

February 7 to March 1, 1927.

Fifty judgments on each pair excepting as noted.

All 100%.		All 98%.	All 96%.	All 94%.
ee — eel *ee — eer* *eel — eep* *eel — eet* *eel — eek* *eel — eed* *eel — eeng* *eep — eer* *eep — eeng* *eer — eet* *eer — eek*	*eer — eed* *eer — een* *eer — eeng* *eet — eem* *eet — een* *eet — eeng* *eem — eek* *eem — eed* *eek — een* *een — eed* *eed — eeng*	*ee — eek* *ee — een* *eel — eem*	*ee — eep* *ee — eem* *ee — eeng* *eep — eem* *eek — eeng* *eeng — eek*	*ee — eed* *eel — een*
90%.	86%.	83%.	82%.	79%.
ee — eet *eep — eek* *eep — eed*	*eep — een*	*eer — eem**	*eel — eer** *eet — eed*	*eem — een**
76%.	71%.	68%.	67%.	59%.
eek — eed†	*eep — eet**	*eet — eek‡*	*eeng — eem**	*een — eeng**

* 100 cases. † 150 cases. ‡ 200 cases.

In this table "100%," *e.g.*, means that *ee* and *eel*, etc., were always recognized, respectively, when they were paired.

itself felt throughout the wall of his thorax and prefers it to every one of nine other songs and hymns, we have good ground for the affirmation: All the better ground in this instance because the subject never knew in advance what was about to be sung. After six weeks, furthermore, he was able to do fairly well at indicating by sign the rise and fall of the singing voice of the experimenter.

All these are so-called "practical" results. "Practical" because, in this case, they have a direct relation to certain situations in the world of education. And that, I believe, is what all science is in its beginnings. It is "practical" in the sense of having a direct relation to human wants. Remoter problems emerge and lay hold upon our attention as experience grows from more to more. In this connection they are beginning to appear.

TABLE IV.

Comparing Lip-reading with Lip-touch-reading.

May 6, 1926. Miss T., experimenter; using two sets of sentences containing ten each, which were of equal difficulty from the lip-reader's viewpoint. Each set of ten sentences contained exactly 114 words. The results are not expressed in terms of per cent. The experimenter gave ten sentences for lip-reading followed by ten for lip-touch-reading.

Number of Stimuli.	Words 114	114	Sentences 10	10
	Correct. Lip.	Lip-T.	Correct. Lip.	Lip-T.
F.	112	100	9	6
N.	43	76	0	4
Cl.	70	79	3	4
Br.	25	51	0	1
A.	40	75	2	4
	290	381 31.3% gain	14	19 35.7% gain
Excluding F., who had been in the laboratory only ten sessions to this date.		57.8% gain		160.0% gain

C., experimenter; using the same two sets of sentences but reversing the order of presentation; that is, giving to another group of subjects ten sentences for lip-touch-reading first, followed by ten for lip-reading.

	Lip.	Lip-T.	Lip.	Lip-T.
K.	47	59	1	3
Bu.	60	78	2	4
J.	45	89	2	3
N.	50	71	1	3
	202	297 47.0% gain	6	13 116.6% gain

TABLE IV (*Continued*).

January 26, 1926. C., experimenter, using two groups of 58 sentences. One group contains 529 words, the other, 507.

Number of Stimuli.	Words 529	507	Sentences 58	58
	Lip.	Lip-T.	Lip.	Lip-T.
	Per Cent.		Per Cent.	
B	49.0	44.9	5.1	10.3
M	39.8	45.4	6.8	6.8
N.*	73.2	81.9	22.4	25.6
Cl	60.7	62.7	15.5	27.5
A	52.5	78.1	15.5	51.7
H	92.0	92.2	67.2	77.5
Ca	55.9	62.4	12.0	18.9
A.*	62.4	92.4	8.6	37.9
Group total	485.5	560.0 15.3% gain	153.1	256.2 67.4% gain

* Took the first 30 of the 58 sentences.
These subjects, excepting Cl., K., Bu., J. and Ca., had had approximately 100 hours of laboratory training before the tests were made.

I have long felt that a contribution is likely to flow from this adventure to the science of neurology. More than this it has seemed to me very probable that the technique I am developing will be serviceable in studying the psychological processes of integration that occur in the course of the development of a language; this for the reason that the method offers an approximately rigid control of the conditions in which we may observe these integrations as they occur in the course of learning a foreign language—and this is the foreignest of all: The vibro-tactile language. There are already indications that my feeling or guess is being shared by others.

What I am reporting at present, therefore, is only upon the edge of a vestibule that leads into a maze of enticing avenues of science. The door is only beginning to be set ajar toward hitherto unrealized capacities of the psychophysical organism for becoming acquainted with its world. Before I conclude this discussion I shall make use of such detailed results as are pertinent to the particular aspects of the general subject that may be in hand.

TABLE V.

Lip and Lip-touch Tests.

January 20, 1927.

1.

		Sentences 58 (A)	58 (B)	Words 529 (A)	507 (B)
Subj.	Exp.	Per Cent. Correct. Lip.	Lip-T.	Per Cent. Correct. Lip.	Lip-T.
O.	G.	15.5	37.9	56.3	74.5
C.	G.	12.0	10.0	44.2	47.3
B.	C.	8.6	20.6	44.2	53.6

2.

		Sentences 58 (B)	58 (A)	Words 507 (B)	509 (A)
Subj.	Exp.	Per Cent. Correct. Lip.	Lip-T.	Per Cent. Correct. Lip.	Lip-T.
O.	C.	53.4	60.3	73.3	82.7
C.	C.	22.4	29.3	60.9	67.2

3.

		Sentences 18 (B)	18 (A)	Words 155 (B)	161 (A)
Subj.	Exp.	Per Cent. Correct. Lip.	Lip-T.	Per Cent. Correct. Lip.	Lip-T.
O.	C.	12.0	13.7	68.3	77.6
O.	C.	6.8	5.1	58.0	60.2

The total number of sentences employed was 116, divided into two lists as nearly equal in difficulty for the lip-reader as possible. These were chosen from the Muller-Walle text for lip-readers. These two lists, called (A) and (B), contain 58 sentences each.

On the morning of January 17, 1927, G., Exp., used 40 from each list during the experiment in the following manner: 20 lip; 40 lip-t.; 20 lip. The following morning he pronounced the remaining 18 in each list as follows: 18 lip; 18 lip-t.

C., Exp., reversing the lists so that the sentences employed by G. for lip-reading were used for lip-touch, etc., began on the afternoon of January 17, 1927, a retest of the subjects O. and C. The order of stimuli was: 10 lip; 20 lip-t.; 10 lip. The following afternoon C. continued in the same manner with an equal number, and concluded the two lists on January 20, 1927, in the afternoon, using the order: 9 lip; 18 lip-t.; 9 lip.

When testing B., C. used the stimuli lists in the same manner as G. had done, excepting that on January 17th he gave 10 lip; 20 lip-t.; and 10 lip. The next afternoon he gave 19 lip; 38 lip-t.; 19 lip.

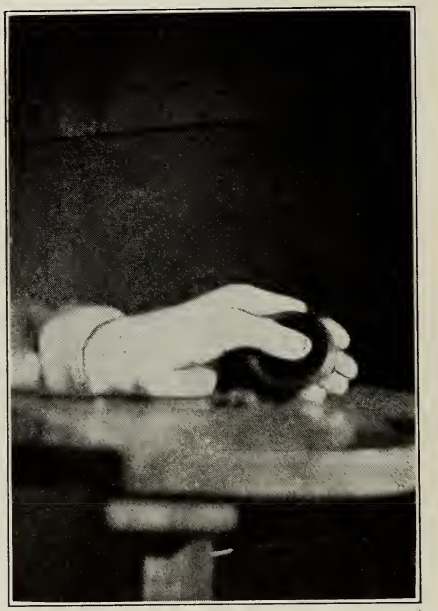
The data in 3, although incorporated in the results shown in 2, are set down separately. Here there were two utterances of each sentence in both the lip and lip-t. lists. One was given with face screened; the other with face exposed. The circuit was on and receivers acting, but they were not touched by the subjects in the lip-reading portion of the test. This method was used to equalize possible auditory cues.

These subjects had had approximately twenty hours of training before the test was made.

III.

Now is the time to describe the means by which the vocal expressions of the experimenter are translated into tactual impressions upon the skin of our subjects. All members of a group simultaneously are equipped with receivers or teletactors which are held in their hands. The subject's finger or thumb rests lightly upon a diaphragm that vibrates with the experimenter's

FIG. 1.



Thumb of a subject resting upon the diaphragm of the single-unit receiver.

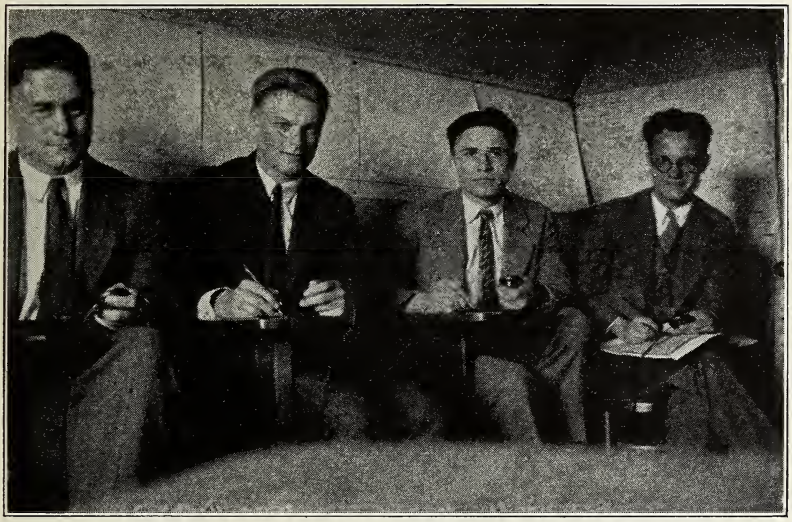
voice. The region of resonance of the diaphragm is around 900 d.v. A carbon transmitter of high quality is at the mouth of the experimenter. A six-volt "A" radio battery, a Philco Eliminator, Power B, as a substitute for the "B" battery, and a Western Electric 7-A three-tube amplifier complete the outfit. All this apparatus, excepting the battery and the eliminator, I have through the courtesy of the Bell Telephone Laboratories.

Unfortunately this method of applying the stimulus leaves some physical factors out of control. It is impossible to be assured that all subjects hold the receiver in precisely the same

way; that is, we cannot know of a surety that they all exert precisely the same pressure upon the diaphragm of the teletactor, and that they are all in contact with corresponding areas upon it. For that matter we cannot be certain that a given subject behaves uniformly in these respects day after day. Such irregularities introduce more or less lack of uniformity of stimulation amongst subjects simultaneously, and in relation to a given subject from time to time.

Once more. I have said that the period of resonance of this

FIG. 2.



Group of deaf subjects at work. Each one holds the receiver in his left hand. All simultaneously receive the same impression.

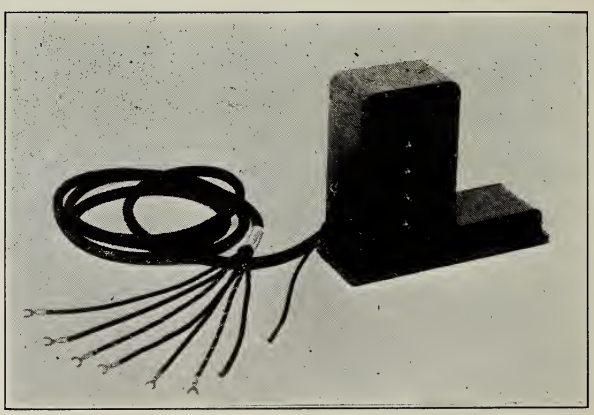
receiver is around 900 d.v. For this reason when one pronounces *ah* as in *father* into the system it comes upon the skin through the teletactor with a great emphasis, because its characteristic frequency is in the vicinity of 900 d.v. also. It is next to impossible to avoid stressing *father,* in the phrase: "My father and mother were Irish," however much one may want to bear down upon *mother.* It is like giving a push to a car that is supported upon ball-bearings. The thing moves and gathers enough impetus in a short space to crash through the wall of a house. Lacking ball-bearings it moves sluggishly and may be brought to a stop by an adverse breeze.

It is impossible to be assured, furthermore, that a given subject constantly maintains the very same area of his skin in contact with the diaphragm. I do not mean to imply a certainty that it is important to do so.

I have said that we are not able to control these factors; and it is impossible, certainly, without harnessing the subject in such a manner as to interfere with the freedom of his responses.

The instrumental situation I have described would be much simpler from the subjects' standpoint if some analysis of the stimuli could be made upon the skin; if, for example, the felt

FIG. 3*a*.

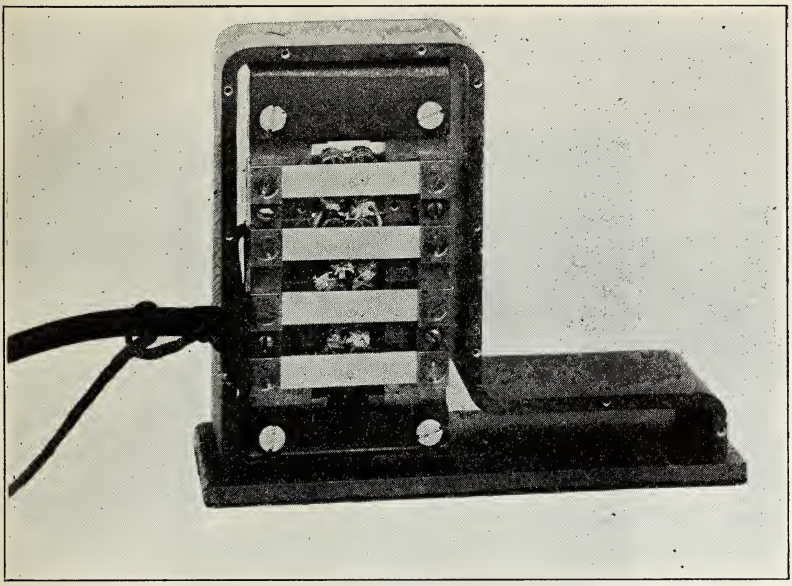


Multiple-unit receiver or "teletactor." The contacts through the housing for the four fingers, respectively. On the reverse side is a contact for the thumb. Each contact is a post set upon the middle of a vibrating reed.

vibrations could be distributed over a large tactual area according to their frequencies. Such an arrangement would add one criterion for discrimination (location of stimulus) to those that are available to subjects who use the receiver I have described. In that case, the instrument upon the skin would perform a function in relation to tactual experience that crudely parallels the function of the basilar membrane in relation to hearing. It would be like grafting an ear upon the skin.

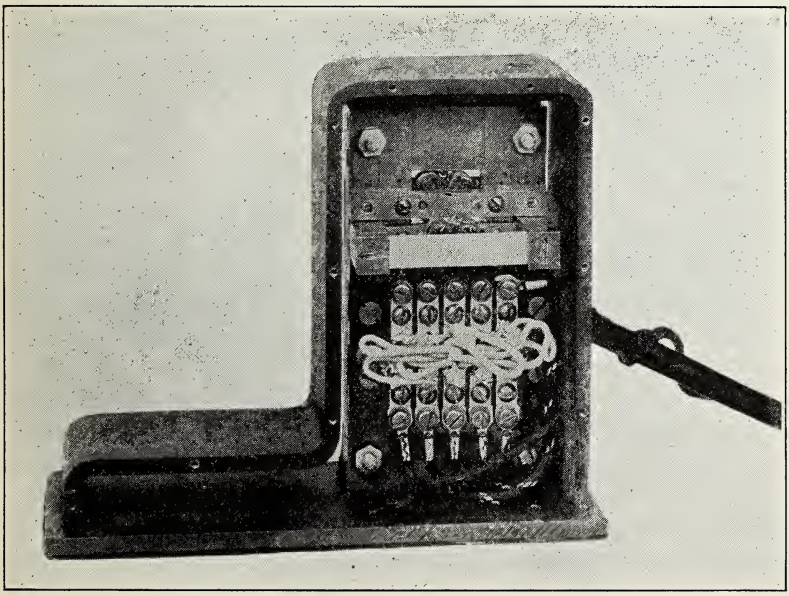
Such an instrument is now at hand. It has been designed and built through the generosity of the Bell Telephone Laboratories. It has five vibrating units, or parts, instead of one as in the older apparatus. It employs a filter to break a certain total range of vibrational frequencies that are employed in speech into five

FIG. 3*b*.



The reeds of the multiple-unit receiver or "teletactor." Four on this side for the fingers, respectively.

FIG. 3*c*.



The reeds of the multiple-unit receiver or "teletactor." One on this side for the thumb.

segments. Those that lie within a given segment up to 250 d.v. operate a unit against the thumb. The segment including 2000 d.v. per second and above operates against the little finger. Inter-

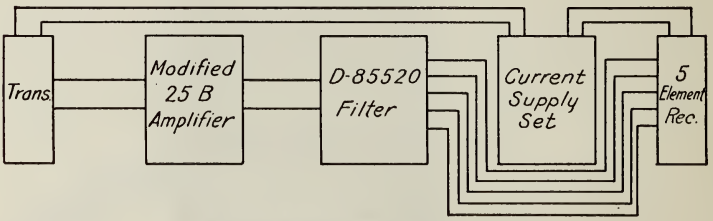
FIG. 4.

Hand of a subject grasping the multiple-unit receiver.

mediate segments, 250–500, 500–1000, and 1000–2000 d.v., actuate units against the remaining three fingers, respectively.

The moving element in each of these parts is not a diaphragm as in the old receiver, but a narrow reed of permalloy upon the

FIG. 5.



Schematic drawing of tactual receiver circuit.

middle point of which there is set a short post of steel one-sixteenth of an inch in diameter. The post works within a round opening in the housing of the instrument, endwise against the skin. It projects one sixty-fourth of an inch beyond the wall of the housing. The reed is so stiff that its vibrating can hardly

be drowned by crowding a finger against the projecting post. The pressure factor, already alluded to, is in no need of control. The post insists upon being noticed. The diaphragm in the older receiver, on the other hand, easily subsides under a pinch. Furthermore, the period of resonance of the reed is near the outer boundary of the sense for vibration. It is beyond the range of the essential speech frequencies. No felt quality of speech, therefore, can catch it like a gust of wind upon the heels of a rising tide and pile it upon a finger. Emphasis of speech, in this teletactor, must keep its own natural place.

In operation the new receiver requires a two-tube amplifier, four six-volt storage batteries or their equivalent, and a source of 110-volt alternating current. All this in addition to a filter.

IV.

So much for the mechanism by which spoken sounds are applied to the skin.

Who are the people who lend their skins to this experiment? Three normally hearing and speaking people who are trained in the methods of psychological research and whose interest is scientific. They are indispensable in analytical work by which we aim to survey the land in advance and lay out the ways of approach. They are employed in sound-proof situations. There have been a total of twenty-seven deaf subjects whose ages range from seven to thirty-five. No one of these has hearing for speech even when aided by an acousticon and amplifier. Their degree of deafness to simple tones ranges from absolute to 50 per cent. Eighteen of these are reported as congenitally deaf.

The laboratory practice that these subjects have had covers from four months to two academic years. Daily work of from a half hour to an hour is the rule. The very minimum number of judgments for record that a subject will make in relation to stimuli in the course of four months is 3000. The minimum in the course of two academic years is 24,000. The least total number of judgments of each of twenty of our twenty-seven subjects is much nearer 24,000 than 3000.

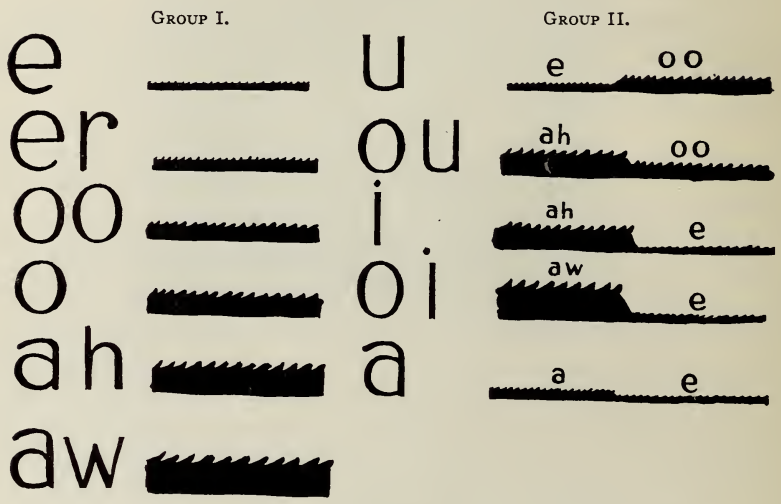
I have made these statements to drive in the point that our cases are no mere novices in our laboratory situation. We are interested, however, in observing what a novice can accomplish in certain experimental situations. I shall report, for example,

how rapidly beginners have progressed in learning to identify vowel and diphthongal qualities by their tactual qualities.

V.

What is the nature of the stimuli? Roughly speaking they are sentences and words chosen from the English language and certain vowel, diphthongal and consonantal elements of words. The elements we have employed to the present are the following vowel, semi-vowel and diphthongal qualities: *e* (eat); *er* (refer);

FIG. 6.



Key to vowels and diphthongs. Indicating relative "weight" and roughness.

oo (boot); *o* (so); *ah* (father); *aw* (aw); *u* (you); *ou* (bout); *i* (sigh); *oi* (oil); *a* (ate). In addition to these are final consonants and two semi-vowels combined with long *e* as follows: *eep, eet, eek, eed, eel, eer, eem, een, eeng.*

How many words in isolation from sentence structure and how many sentences have been employed in our numerous types of exercise? In the aggregate they mount to several hundreds. A deal of specific drill has been had in relation to 66 isolated words and to 120 sentences that have been systematically chosen for the purpose.

Details are not lacking as to the way in which vowels roll over a finger. In relation to hearing, vowels and diphthongs are the energy carriers. So are they through the teletactor in relation to

the tactual sense and the sense of vibration. Our subjects themselves have described the six vowel qualities I have mentioned in terms of their intensity or "weight," as they say. From *e* to *aw* is an increasing order of weight, *e* is lightest and *aw* is heaviest. In exactly the same order they have ranked these qualities in terms of roughness to the feel: *e* is smoothest and *aw* is roughest. I am referring now to twenty deaf subjects, each of whom made approximately 3800 judgments while he was arriving at this description. At the end there was practical unanimity amongst them in respect to their judgments of relative weight (intensity) and roughness. They used these criteria very successfully in their attempts at identifying vowel and diphthongal qualities by their feel. The measure of their success at the completion of the drill is indicated by 80 per cent. to 100 per cent. of a perfect score.

We have undertaken to discover in how short a time a deaf subject who has never heard human speech and who has had no previous laboratory practice of this nature could learn to make use of these tactual characteristics in the identification of the vowel and diphthongal qualities I have mentioned. For this purpose we selected a young woman twenty-two years of age and began intensive work with her on October 16, 1925. In the course of twenty sessions of a half hour each she learned to identify ten of the eleven qualities I have already quoted (excluding only *ah*) in 83 per cent. of instances. During this period she made 1200 judgments for record. She had not the advantage of the graduated order of weights and roughnesses of the vowel qualities to which I have alluded, at any rate her attention was not called to them.

On March 25, 1926, we undertook the same intensive program with a congenitally deaf boy aged twenty-three, who up to that time had never been inside the laboratory. He had the advantage of the description of qualities I have mentioned. The experimenter over and over again brought them to his attention. In twelve sessions (720 recorded judgments) he attained an accuracy of 83 per cent.

These experiences admit at least an initial ray of light through a crack in the shutter upon the ever-recurring question: "How rapidly can one learn to use the tactual criteria of speech?"

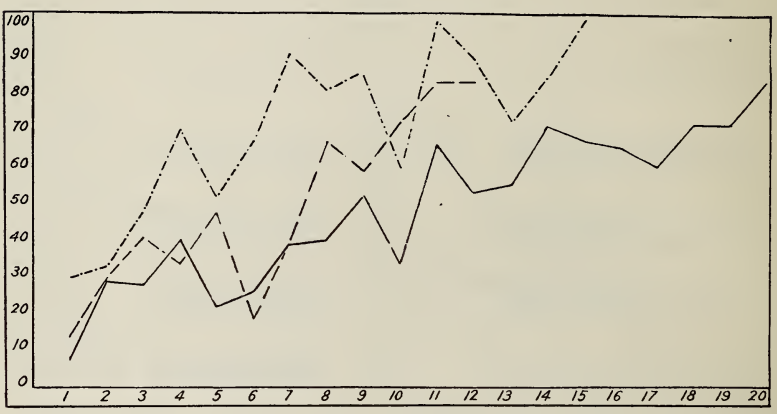
The five diphthongs, mentioned above, our subjects recognize

as combinations of the roughnesses and weight of vowel qualities. Thus *u* combines *e* and *oo*.

From my own experience as a hearing subject in these experiments I feel sure of only one change that I would make in the order of the vowel qualities I have mentioned. To repeat, the deaf subjects ranked them in order of weight and roughness: *e, er, oo, o, ah, aw.* I would make *er* and *oo* change places.

It is certain that the roughness of these qualities and their intensity, too, in parts of the series at least, has a relation to the

FIG. 7.



Learning curves on ten vowel and diphthongal qualities. Three subjects. Figures in the horizontal line represent successive laboratory sessions of approximately thirty minutes each. Figures in vertical column indicate per cent. of perfect identification. The two lower curves represent the experience of subjects who were just beginning their laboratory practice. The uppermost curve represents the progress of a subject who had just returned to the laboratory after an absence of two semesters, prior to which she had had tactual training of this nature during an aggregate of approximately thirty hours.

character of the receiver. Even so, it will be observed that the order I have quoted approaches very closely to that of fundamental frequencies that characterize these vowel qualities. I refer to Crandall.[1] He found the mean fundamental frequency and the mean low characteristic frequency of four male voices and four female voices given in Tables VI and VII.

It is improbable that there is a great difference between the figures of Crandall and the corresponding frequencies of the experimenter's voice in our laboratory. It will be noticed that if *oo* were placed over *e* in the scale our deaf subjects' description would correspond exactly to the descending order of fundamental

[1] "The Sounds of Speech," *Bell Sys. Tech. Jour.*, 4, No. 4.

frequency according to the figures in the table. I have alluded also to the fact that, relying upon the story of my own fingers, I should make *er* and *oo* change places. Not only so, but I have lately found deaf subjects who, without my asking them for a judgment, have expressed the opinion that *oo* is lighter upon the finger than *er*. Thus do our approximations grow and grow.

Of course I understand that one in the east and south and midway between is playing with an ammunition dump when one handles this much-knocked-about *er*. Some of us ignore it in speech, others tip our hats to it and still others grind it with an

TABLE VI.

Mean Fundamental and Mean Low Characteristic Frequencies.

	Male Voices.		Female Voices.	
	M. F. F.	M. L. C. F.	M. F. F.	M. L. C. F.
e	136 d.v.	296 d.v.	252 d.v.	332 d.v.
er	131	570	239	712
oo	140	411	270	581
o	116	520	237	729
ah	113	955	234	1036
aw	112	722	243	801

ominous sound. As to the other qualities in our list, there are individual differences, too, in the matter of pronunciation, and it is improbable that any one of us holds absolutely from day to day to a fixed mode of uttering any one of them. But in spite of these inequalities our subjects get ahead. Not even the voices of strangers foil them. Thus the average of a group of six cases fell off from 73 points on a scale of 100 to 53, and a group of five fell from 80 to 53 when complete strangers were pronouncing sentences into their fingers. This is altogether encouraging in view of the fact that no one of the groups had had more than seventy hours of training prior to the test. This statement relates to a situation in which sentences are the stimuli and in which the swing of speech is a factor in recognition. This we demonstrated two years ago. Much more recently we have shown that it obtains also in relation to the very much simpler and more difficult situation when the stimuli are vowel and diphthongal qualities and when a woman's voice is substituted for a man's.

It is entirely probable that subjects find some criteria in addi-

tion to intensity and roughness. I am thinking of a felt pattern of vibrations that they may obtain from the diaphragm of the receiver. For when it is vibrating freely in the air it falls into a pattern—no two alike when a series of vowel qualities, *e.g.*, are spoken into the transmitter. The novice can see these patterns with his unaided eyes. If he will sprinkle a powder lightly and evenly over the diaphragm of a receiver in a horizontal position

TABLE VII.

Order of Difficulty in Recognizing Certain Vowel Qualities Taken Two at a Time.

G. Subject, January 31 to February 3, 1927.

50 judgments on each pair.			On February 7, 1927, G. repeated 50 each
	Per cent.		
1 — *e* — *o* —	100		
2 — *e* — *ah* —	100		On February 7, 1927, G. repeated 50 each
3 — *e* — *aw* —	100		
4 — *oo* — *o* —	100	1	Per cent.
5 — *oo* — *ah* —	100		*er* — *oo* — 80
6 — *oo* — *aw* —	100		*ah* — *aw* — 76
7 — *er* — *aw* —	98	2	
8 — *er* — *o* —	96	3	
9 — *e* — *oo* —	96		
10 — *o* — *ah* —	92	4	
11 — *er* — *er* —	90		
12 — *er* — *ah* —	90	5	
13 — *o* — *aw* —	90		
14 — *er* — *oo* —	60	6	
15 — *ah* — *aw* —	54	7	

100% means that *e* and *o*, *e.g.*, were recognized, respectively, in every instance in which they appeared.

and speak into the microphone end of the system, the skin of powder dances about and settles into a figure, now one and now another, depending upon the vowel quality that he is uttering.

Can the subject catch these vowel patterns on the wing? The physicist replies that they change profoundly the moment ever so light a pressure is brought to bear upon the vibrating element. Nevertheless, if I may anthropomorphize, it doubtless tries to vibrate according to its nature and incipiently it does so. Is it possible that the touch organ may seize upon the incipient figure? The question raises doubts, but let us not shut the door.

Certain variations amongst subjects' reports may be due in some measure to the fact that one has succeeded in catching some of the details of a pattern and that he throws these criteria into the hopper along with distinctions of intensity and roughness, while another fails to pick them up. He must do his business of judging, therefore, with a small range of capital: With fewer criteria than his neighbor has at his command. Thus one subject finds *oo* one of the most easy qualities to discriminate from the other ten in the list. For another, working simultaneously, it is one of the most difficult; this may be for the reason, in part, that one catches the pattern while another does not.

In the preceding discussion I have had in mind the single-unit receiver. It is of essentially the same order as the ear-piece of a radio set. As to the new five-unit teletactor already described, it yields a pattern without question. But no post or immediate stimulator alone does it. The posts plunge against the skin, some more distinctly than others, and some less, depending upon the segment of frequencies that actuates it. A given post acts with more or less intensity, depending upon its driving power at a given moment: Whether it comes from a higher or lower section of its corresponding segment of frequencies. Two or more of them acting in succession or simultaneously present a pattern. Thus, to take a hypothetical example which, by the way, is not true to fact: The word *a* is a diphthong. In uttering it we begin with a low frequency and conclude on a higher level. Suppose the frequency at its beginning is below 250 d.v. and at or near its ending between 1500 d.v. and 2000 d.v. Assuming that no other frequency segments are represented, this word—diphthongal quality—will be felt first upon the thumb and last upon the fourth finger. Its pattern, then, is 1–4 (if the figures represent the fingers of the hand, including the thumb). These patterns may be very simple or very complicated. Complicated, for example, when a given utterance is represented upon all the fingers and thumb of a hand. But the limit of complexity is not found within these boundaries. For not even a vowel quality is represented by the activity of one unit alone upon its corresponding finger. The fundamental and an overtone are represented. The fundamental is felt distinctly, the overtone more faintly. Together they very often make a recognizable pattern.

VI.

Now I shall venture a prophecy in my own country. The use of the tactual sense and the sense of vibration by the method I am developing may yet be an independent avenue for the reception of speech by the deaf. We need to assume only that "listeners" through the skin may be equipped for teletactile audition not during only a half hour daily, but throughout the successive days of school terms.

Apart from this the method, as a supplement to lip-reading, will speed up the processes of instruction and learning generally in schools for the deaf. It will greatly facilitate the process of developing speech amongst mutes and semi-mutes. It will provide a new tool for our use in studying the psychological problems of integration in language development. It will contribute very interestingly to the psychology of meaning and of sensation. Its usefulness will be limited only when, if ever, it is appropriated and made the exclusive property of doctrinaires.

Only the first of these forecasts. I have already stated that we have talked to the skin of our subjects until two of them have been able to pick up new connected discourse by this means independently of hearing. Six times we have demonstrated that the feel of speech added to seeing it through the eyes of a lip-reader as much as doubles one's capacity to interpret what is being said. We have shown that by dint of repeatedly feeling connected speech one becomes acquainted with rhythm, varying tempo, emphasis, accent, pitch and pattern—all of which together carry meanings to you and me. Through these ways and by-ways the deaf find great aid in the reception of speech.

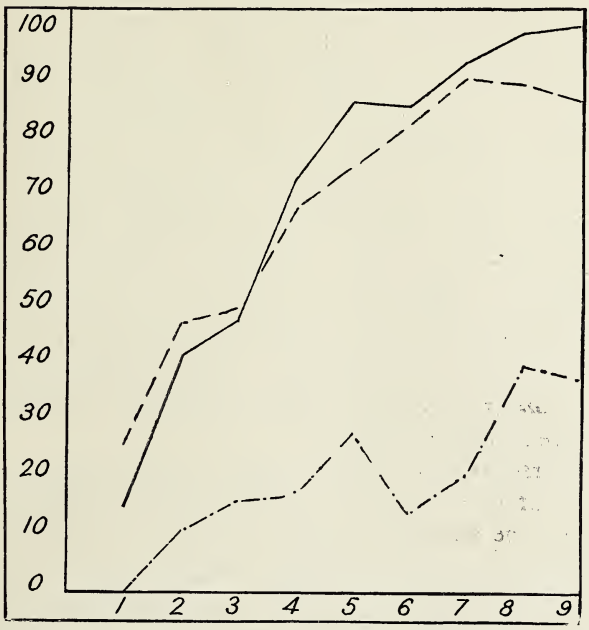
Beyond this they get a new grip upon their own vocal expression both as to enunciation and the lilt of speech. They improve themselves in the art of silent reading. And along with all this and upon a par value with it all comes increased enjoyment of speech.

The limits of this enterprise are determined wholly by the number of criteria of speech that are available through the sense of touch. By this gateway one can obtain more signs of the meanings of speech than can be got by observing the face of a speaker. This statement I make without hesitation.

I have already shown that vowel and diphthongal qualities

which carry the energy of speech can be learned by touch. I have reported also upon a preliminary experiment on the tactual identification of consonantal qualities following the long vowel *e*. The signs are convincing in this relation. Combinations of consonants with a long vowel like *e* can be tactually identified. But I am inclined to think that we are disposed to exaggerate the importance of consonants even in hearing speech, not to speak of feeling

FIG. 8.



Learning curves showing the progress of three subjects in learning 120 sentences by their tactual patterns. Figures in horizontal line indicate successive laboratory sessions. The two highest curves represent subjects who had had an aggregate of approximately 250 hours of laboratory practice. The subject who made the lowest curve had had approximately sixty hours of practice.

it. As a matter of fact, the two cases who, last May, were able to pick up a story from its feel through a single element receiver had had no systematic training on the consonants. Casually they picked up what was sufficient. The feel of intervals and stops had got into their bones, so to speak, and these sufficed as signs of consonants.

They had become saturated with the patterns of sentences and of phrases. They had learned that from a third to one-half

of colloquial sentences are concluded by prepositional phrases and the patterns of such phrases they are able to absorb.

Other tricks of their trade had been brought to their attention through scores of examples. For illustration, the word *you* is easily recognized by trained subjects. Whenever it is spotted as the third word in a sentence they know at once that it is immediately preceded by one of a few such words as *can, do, will, have, did* and *are*. They know that the first word is such as *how, why, when, where* or *what*. They know that the fourth word is a verb and that the sentence is a question. All that is a good deal to know at the start. It affords them a good spring-board from which to dive at some meanings. The recognition in addition of a few vowels or diphthongs here and there is extremely likely to bring the whole sentence train in on schedule time.

These few details may suggest, even though vaguely, how sentence patterns may be built up in a receptive organism, and psychologists will appreciate the statement that the reaction to such patterns may become thoroughly automatized, as they are in relation to hearing. From my own limited personal experience as a subject in the laboratory I can testify that automatizations similar to those I now have in mind do occur and that they occur early in the course of practice.

As a matter of fact, when one talks about building up sentence patterns through the sense of touch and making them automatic, one is talking of the very thing that is going on in every normally equipped little toddler in our homes. The youngster is getting his patterns, however, through his ears rather than his fingers. That is the only difference. He is becoming ear-minded instead of finger-minded. But if my finger-mindedness can tell me as unerringly as my ear-mindedness can that I have burned out a crankshaft-bearing, I have, so far, no occasion for quarreling with my fingers. There is nothing sacred about signs. As the psychologist (and every other one of us) sees words, they are so many signs of meanings. "Wie befinden Sie sich?" will do as well as "How do you do?" The feel of a piece of silk may tell you as much as a paragraph can do. I care less for a sign than for its meaning.

In numerous discussions concerning this experimental enterprise considerable stress had been laid upon the extreme niceness

with which the ear can make discriminations amongst the simpler sounds of spoken language and of music. In these connections the grave question has been raised: "Can the skin begin to approximate the ear in adjustment to refined differences amongst intensities and tonal pitches? Consider the frequencies of tonal vibration that occur when only the vowel qualities are uttered! For the male voice scattered frequencies run up to the height of 3800 a second and for the female voice to 4800." [2]

Very well then, as to intensities: Discriminating by feel amongst intensities of vibration against the skin. In this case the organs of touch can do as delicate a piece of work as the ear. If by ear one can make 100 distinctions of loudness between a higher and a lower limit, so can one by touch. I make this statement on the authority of Dr. V. O. Knudsen, whose unpublished paper has already been referred to.

But what about frequencies of vibration that correspond to the pitches of tones? Here the skin lags behind. Doctor Knudsen did not find that the skin can sense a higher rate of vibration than 1600 d.v. a second. The highest figure that has ever been published in this connection is 1552, and that by Landlois in his "Lehrbuch d. Physiologie d. Menschen," 1880. But 1600 is too low. For on the ninth, tenth and eleventh of March, 1927, I succeeded in proving that each one of three deaf subjects on whom the test has been made can by touch sense vibrations of 2000 d.v. or above. I have already explained that the fifth post or button on the teletactor vibrates with the reed to which it is attached *only* in frequencies of 2000 d.v. or more. In more than 80 per cent. of cases they sense a vibration when long *e* (German *i*) is pronounced. It is not only an initial surge of the vibrating unit that is felt, but a continuous vibration when long *e* is drawn out. In approximately one-half of instances they catch a vibration of the same post when *er, ah* and *aw* are pronounced. Very soon, I think, we shall be able to determine just how far above 2000 d.v. they can go. I ought to say here that the stimulus was habitually received by hooking a finger-nail solidly over the post. But the vibration can, nevertheless, be got against the skin directly.

[2] Crandall, *op. cit.*

According to Crandall's figures the frequencies above 2000 that occur in relation to these vowel qualities are as follows:

ee	2987
er	3050
aw	3612
ah	3683

The above qualities were sensed through the 2000 plus reed, more or less frequently by all subjects. Our generally most successful deaf case, on the other hand, never sensed *o* and *oo*. According to Crandall, once more, these qualities have frequencies above 2000 as follows:

o	3475
oo	3700

Observe that our subjects are most successful in detecting *e* on the 2000 plus reed. Its high frequency is but little under 3000 d.v. on the basis of Crandall's table. Other investigators have reported frequencies above 2000 for long *e* as follows: Donders (1870), 2816; Helmholtz (1863), 2304; König (1870), 3760; Miller (1916), 3100; Modell and Rich (1915), 3744; Köhler (1909), 3480.[3]

So much for the upper limit of tactual sensitivity for frequencies. The lower limit is as low as that for hearing.

These data in themselves offer great encouragement in this research. For the frequencies that are essential to the under-

[3] Since this paper was written and read we have used an oscillator through a single unit of the teletactor system at a time to determine the highest frequency that can be detected tactually. At each of several frequency stages from 150 d.v. to 2600 d.v. inclusive we have found the threshold for the sense of touch and have recorded the corresponding dial settings. Subsequently we have repeated these settings, and with a depth-gauge have measured the displacement of the vibrating element at each successive stage. These measurements afford the data for a "tactogram." Below (Fig. 9) are two such "tactograms" based on introspections by the author. These are based upon two series of observations: One was made when the stimuli were received against the end of the nail (left index) against the vibrator, the other when the stimuli were upon the skin near the tip of the same finger. Another subject, who received the stimulus only against the nail of the small left finger reached to the frequency of 2700 d.v. The thresholds for these two observers are not widely different. The hump in the curves is near the region of resonance of the vibrating reeds.

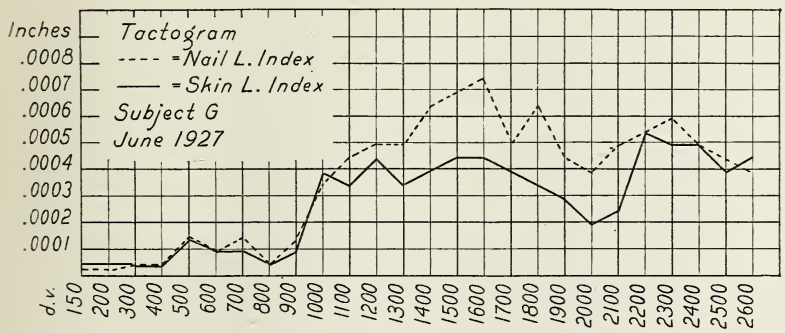
Our next step in this connection is to measure the displacement of the vibrating element *while the finger is in contact with it* by means of a microscope equipped with a micrometer eye-piece.

standing of speech by ear lie far below the uppermost of these limits.

Apart from all this is the question: What is the degree of refinement with which the organs of touch can discriminate differences of vibrational frequency? Doctor Knudsen, in the work already referred to, says that the rate of vibration must change by as much as 15 per cent. to 30 per cent. before a difference can be noticed tactually. How much more refined is the ear that can pick up differences of three-tenths of one per cent.!

Our preliminary results, on the other hand, prove that differences of 9 per cent. can be sensed. This applies only as far as

FIG. 9.



we have gone to the present; that is, up to 600 d.v. The stimulus was applied to the ball of the thumb through the single-unit receiver with a diaphragm, which has already been described. Through the courtesy of the Bell Telephone Laboratories we are able to use an oscillator in connection with this phase of our work. By means of a depth gauge we have determined that the displacement of the vibrating diaphragm over the range we have covered is 0.001 inch with practically no variation. It yet remains to be seen what can be done in this direction by means of the new teletactor.

These results are of more than ordinary scientific interest, I am sure, falling as they do upon the frontier of a pioneer state. Truly we are not yet aware of the utmost limits of the capacity of the human organism to adapt itself to external stimulation. I have already suggested that we have by no means sent a plumb line to the bottom of the possibility of substituting one organic function for another.

Running again to the practical aspects of this enterprise: To the question how far we can go through the senses of touch and vibration toward developing a language sense in its several implications. We must forget a deal about the hearing of speech. We are biased toward our whole mountains of data relating to the physics and physiology of hearing. Our practical question is not whether through the skin we can distinguish frequency differences amounting to one-third of one per cent. as we can by ear, and whether we can sense frequencies running up to ten, twenty or thirty thousand vibrations a second. The real question is: "Can we get enough criteria through the old gates in the skin?" Well, the energy of speech is carried by frequencies below 1200 d.v. for a certainty. We can make out more differences of frequency than Doctor Knudsen's figures indicate. The feels of vowel and diphthongal qualities are separated one from another. We can repeat this statement with relation to at least many combinations of vowels and consonants. We can distinguish time intervals, the changing tempo of speech, emphasis, accent, rhythm and pattern. Can we put these criteria together in enough different ways to make up as many signs of meanings as we require to understand the lost art of conversation?

If we have but ten apples in a row we can shift them about till we have counted more than three million arrangements.

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